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PROJECTILE FOUNDATION MOMENT GENERATION- PHASE III

BATTELLE PACIFIC
NORTHWEST LABORATORIES
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This report documents the work performed during the third year of a multi-year project aimed at understanding the physical and mechanical characteristics of a typical nylon obturator band as it reacts to the balloting (wobbling) motion of a projectile traveling down a gun barrel. In particular, the resisting or foundation moment generated by the nylon obturator as the projectile cocks in bore were investigated. Past year's efforts have centered upon gaining an understanding of the basic mechanics of this type of motion, and have been constrained to one projectile/band geometry.

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20. Abstract (cont'd)

This year, we were able to extend the experiments and analysis to different band geometries. In particular, we were able to model a geometry very similar to the obturator of the current 120mm APFSDS projectile. Results from the experiments and analysis show that, although the foundation moment of a band with this geometry is less than that of a straight band, the moment is still large. The conclusion has been made in past years that the foundation moment is probably the dominant force on the projectile early in the ballistic cycle. The current work substantiates this result, and extends it to include representative geometries for projectile obturator bands.

One of the conclusions from the work done last year to estimate foundation moment was that the non-linear material behavior of the nylon band was very important to that estimation. Therefore, this year's work included the measurement of the mechanical properties of the nylon materials under quasi-static conditions and simulated ballistic loading conditions. These properties were then included in the analytical estimation of the foundation moment. A companion report, titled "Evaluation of the Deformation Behavior of Nylon Materials Used in Ballistic Applications," was generated within the funding for the foundation moment project. The results of that study are appropriate to a wider range of applications than the results of just the foundation moment study, and as such are reported separately.

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INTRODUCTION

This document reports the results of the third year of an ongoing study conducted at the Pacific Northwest Laboratory under the sponsorship of the U. S. Army Ballistic Research Laboratory. The purpose of the study has been to investigate and characterize the restoring or foundation moment generated by the nylon obturating or rotating band of a single bore contact projectile undergoing balloting (wobbling) motion. The inherent transverse stability of the projectile is directly affected by the magnitude of this moment. As such, the design of a single bore contact projectile (or for that matter any projectile with a large obturator or rotating band) will be directly affected by the results of this project.

The major conclusion reached from the first two years of this project was that the foundation moment is indeed large. The magnitude of the moment is similar in magnitude to the upsetting moment that exists at a projectile's maximum acceleration, if the center of gravity of a projectile is approximately two thirds of a caliber behind the center of rotation of the projectile. Indeed, early in the ballistic cycle, before the projectile reaches maximum acceleration and base pressure, the foundation moment is most probably the dominant force on the projectile. This means that a projectile with its center of gravity located axially at approximately the center of transverse rotation could be designed to be inherently stable during launch.

Another conclusion reached from the second year's effort was that it is very possible that the finite element method may not ultimately be the best design tool for modelling the projectile's response to transverse motion. This is not to say that it is the wrong tool for this work, just that further development of such a tool is required before it becomes cost effective. The finite element method is, today, the only such tool available to the sabot designer. Certainly, the material non-linearities of the nylons commonly used for obturator bands would have to be taken into account in any such analysis. Modelling the material as linear proved to overestimate the foundation moment by a significant amount. In most cases this overestimation was more than twice the measured moment.

Several factors influencing this estimation were discussed in the report last year including material non-linearities, circumferential mesh refinement of the finite element models, and boundary condition modelling. In this year's work, the circumferential element size was more refined, and non-linear material properties were used in the analysis. These analytical results match more closely the experimental results obtained from this year and last year, but are still quite high. This is evidently due to the difficulty in precisely specifying boundary conditions for the finite element models. Whether or not all of the obturator or rotating band will be in contact with the gun barrel at all times is still in question. Certainly, in our low pressure tests, all of the band is not in contact at all times. In an actual gun firing, the pressures are considerably higher, and quite probably the entire obturator band would be in contact with the gun barrel at all times.

This is the nature of the boundary condition modelling problem, and why it is difficult to precisely know how to specify a consistent set of boundary conditions for the finite element analysis.

A large question still remains, as stated above, about the efficacy of the finite element method for estimation of foundation moment. The problem size and required computer time to perform a full three dimensional non-linear analysis of a complete projectile may be prohibitive. The model projectiles analyzed and tested in this project have been very simple in geometry, and all of one material. Traditional APFSDS projectiles are considerably more complex, and would require a much larger model and correspondingly more expensive analysis to estimate the potential foundation moment. A very exhaustive study of alternatives to the finite element method for this estimation should be made before BRL adopts the method for this particular application. This is being done to some extent already with ongoing work at BRL.

EXPERIMENTAL APPARATUS AND TECHNIQUES

The experimental apparatus, shown in Figure 1, is the same as was used last year. The projectile launching device shown in Figure 1 was constructed during the previous year and the reader is referred to the report for last year for a complete description of the device. The following description is relatively sketchy.

The receiver tank to the rear of the projectile (to the left in Figure 1) is a piece of six inch diameter schedule 40 steel pipe with a domed pressure cap at its left end and a flange at its right end. This flange is mated with an identical flange welded to the breech end of a section of gun barrel containing the test projectile. A ramp-like deflection induction/moment measurement device is placed in the gun barrel after the projectile is forced into the breech opening. This ramp-like device resides behind the nylon band on the center of the projectile, and in front of a faceted end plate on the rear of the projectile.

The gas pressure receiver tank is bolted onto the rear of the gun barrel, and gas pressure is applied to the receiver. This gas pressure (we use a nitrogen bottle) builds up behind the projectile, causing the static friction of the nylon band to be overcome, and the projectile accelerates down the gun barrel. This results in the faceted plate attached to the rear of the projectile being pulled over the top of the ramp.

The faceted end plate which is attached to the projectile is machined very precisely, with the facets at precisely measured distances from the center of the plate. The plate thus can be placed on the projectile in such a manner as to input a known deflection to the rear of the projectile as the projectile is caused to ride over the ramp. There is a rod under the ramp in the gun barrel which goes through an airtight fitting and actuates a piezoelectric force transducer mounted beneath the gun barrel. This force trarsducer is used to measure the force required for the projectile to be deflected by the known amount described above. The output from this force transducer is recorded using a Nicolet Digital Oscilloscope. This output, taken with the known deflection gives us the foundation moment for a specific angular disturbance.

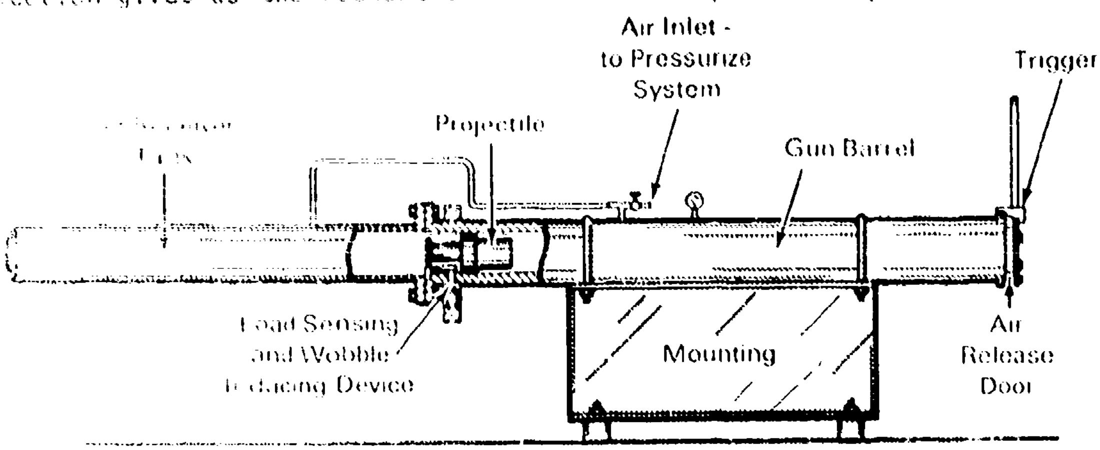


FIGURE 1. Projectile Launching Device

The above is again a simplified discussion of the experimental apparatus and technique used for this year's work, but it describes the key features of the system and the quantities measured. The main parameter investigated for this year's testing was the geometry of the band itself. The tests from the previous year gave us a good indication of the magnitude of the foundation moment for a single band geometry, but were not representative of the geometry of a typical APFSDS projectile, as described above.

Figure 2 is a schematic of the four band geometries tested this year. The band identified as Band A in the figure is a replica of the bands used for the first two years of testing. This band was used to verify the experimental apparatus and techniques, and was used as a control in the experiments. The second two bands, B and C, should be thought of as transitions between the original band geometry and what is typical of the current 120mm APFSDS obturator band. The fourth band, band D, is very similar to the current 120mm obturator. Each of the bands was machined with approximately a 10 mil interference between the outer diameter of the band and the inner diameter of the gun barrel surface. This was done in an attempt to keep as much of the band in contact with the gun barrel as possible. The portions of the band which lose contact with the gun barrel surface are no longer providing a foundation, and therefore do not contribute to the foundation moment. The analysis that has been performed using the material properties of the nylon bands assumes full contact with the gun barrel at all times. This is most probably the case in an actual gun firing, but not necessarily the case with our tests. As stated above, a Nicolet Digital Oscilloscope was used to record the output from the Kistler Load Washer mounted below the ramp device. This year, an oscilloscope with a floppy disk drive was available for the testing. Therefore, all of the tests for which data was captured were recorded on the floppy disk, and subsequently plotted. An appendix of this report contains the output plots for each of the recorded events. Also this year it was discovered that the temperature of the assembly had a significant effect upon the outcome of the tests. If we ran the tests in the afternoon on a hot day, the magnitude of the tested foundation moment would be considerably less than if the tests were run in the morning, when the assembly was cooler. We decided that this was most probably due to the expansion of the gun barrel itself, as the projectiles were stored inside a heated office, and their temperature did not vary. Once this effect was discovered, the rest of the tests were run before 9:00a.m. in an attempt to provide consistency in the test results, and to minimize the effect of the band losing contact with the gun barrel.

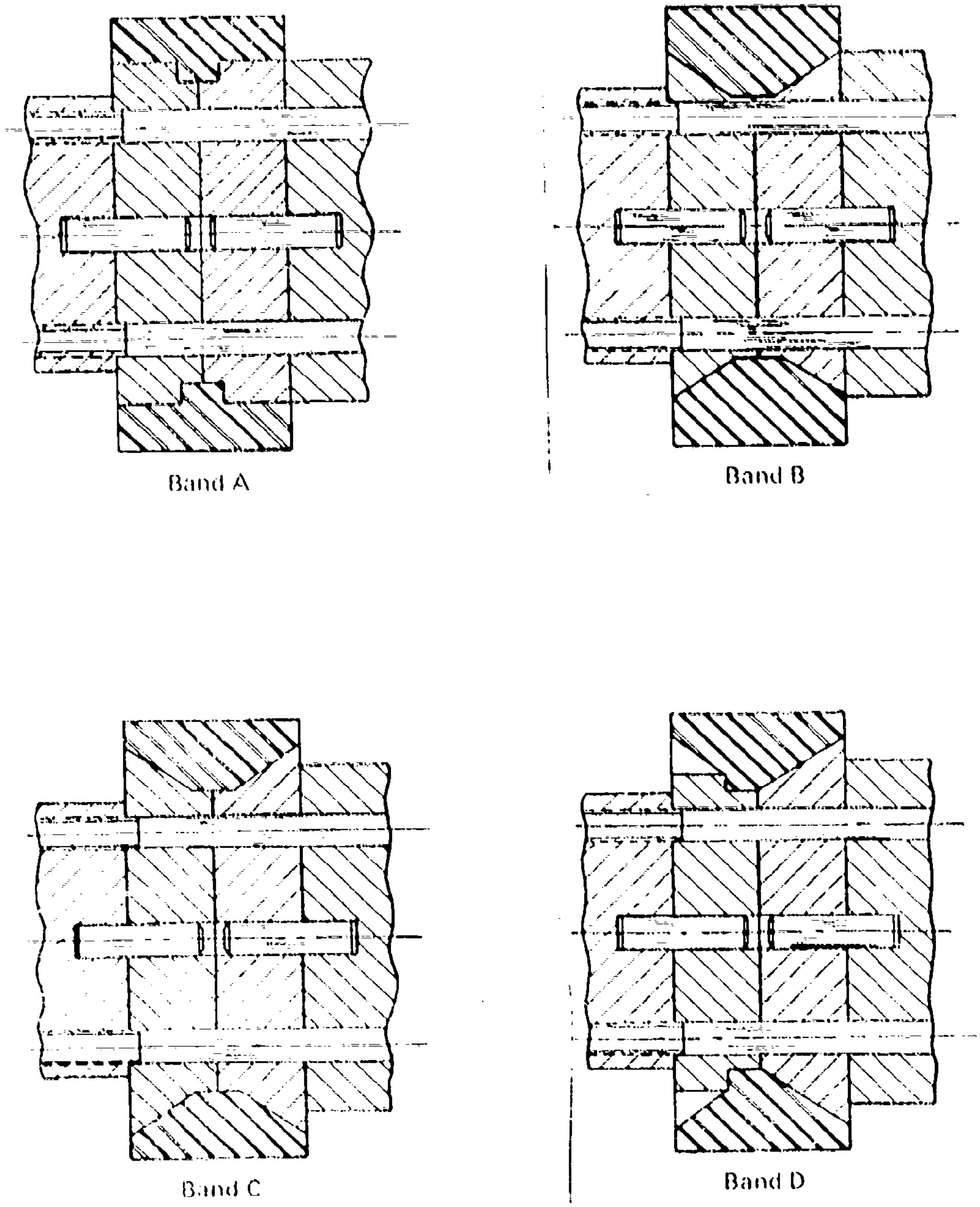


FIGURE 2. Schematic of Four Band Geometries

TEST RESULTS

A total of twenty bands were manufactured for this year's testing, five of each design. The bands were manufactured with a nominal 0.01 inch (.25mm) interference between the outer diameter of the band and the interior gun bore diameter, as stated before. Some of the bands had less than this amount of interference. It was originally our intention to have a somewhat larger interference this year than the 10 mils used last year. A lack of correct communication between the researchers and the machine shop resulted in inconsistent band diameters. This is one of the realities in which any experimental program must live. A table with band diameter measurements before and after tests is included as an appendix to this report. These measurements are only approximated, and do not seem to correlate to measured foundation moment.

Of these twenty bands, reliable data were collected for sixteen (16) tests. Band design A (the band like last year's band) had the least number of successful tests, with only two reliable data points (one of the unreliable data points saturated the scope, with a reading of more than 5000 pounds force). Most of the other tests provided reliable data, with the exception of test 2-C (test 2 with the C band), in which the scope triggered before the firing event. A re-setting of the triggering level solved this problem, and the rest of the tests provided good data.

Another problem that we had initially was that of loading the projectiles into the gun barrel. After the first test, in which more than 600 psi was required to fire the projectile, we applied some silicone lubricant to the inside of the gun barrel, and the projectiles loaded much more easily. It also required significantly less gas pressure to fire the projectiles with the lubrication. With a lubricated barrel, a third of the gas pressure, or only about 200 psi, was required to fire the projectiles. The muzzle end of the gun barrel also required some lubrication, as some of the projectiles stuck in the barrel during the tests, especially with the reduced firing pressure. This lubrication of the gun barrel did not seem to have an effect on the measured moment however, as the magnitude of the moment from Band A with a lubricated barrel was very similar to the magnitude of the measurements taken last year in which there was no lubrication. It seems that friction plays only a very small role if any in the foundation moment. This result is consistent with some findings from the first year of this project, and the fact that the sliding friction coefficient of nylon against steel is nearly negligible.

The raw data output from the 20 tests is shown in Table 1. Each of these tests was run at an input displacement of approximately 0.09 inches (2.3mm). Note that Table 1 also includes some additional notes about each of the tests, and which of the projectiles stuck in the gun barrel. Table 2 is a reduction of the data presented in Table 1 which gives the average force for each of the bands, and the foundation moment associated with that force. Note that the test output seems to indicate that bands B and C would provide higher foundation moment than band A. The failures of three of the band A tests to provide reliable output probably can account for this discrepancy. Test 3-A is included in the average below, as 5000 pounds. The actual force which was

TABLE 1. Raw Data From Tests

Test No.	Gas Seal No. - Version	Heise Reading at Firing, psi	Load MV = Load	Radii Disk Setting	Storage on 5-¼" Floppy Disk # - Channel #	Date Tested	Additional Notes
1	1-A	620	No Data	2		8-9-84	
2	2-A	220	No Data	2		8-9-84	Stuck in Barrel
3	3-A	190	Saturated Scope Over 5,000 lbs				
4	4-A	215	908 MV = 4540 lbs	2	1 - 1	8-13-84	
5	1-B	170	946 MV = 4730 lbs	2	1 - 2	8-13-84	
6	2-B	175	880 MV = 4400 lbs	2	1 - 3	8-13-84	
7	3-B	145	1050 MV = 5250 lbs	2	1 - 4	8-13-84	
8	4-B	245	1044 MV = 5220 lbs	2	1 - 5	8-14-84	
9	5-B	190	1052 MV = 5260 lbs	2	1 - 6	8-14-84	
10	1-C	120	1078 MV = 5390 lbs	2	1 - 7	8-14-84	
11	2-C	200	No Data	2		8-21-84	Triggered before release
12	3-C	160	1028 MV = 5140 lbs	2	1 - 8	8-21-84	Stuck in Barrel
13	4-C	172	966 MV = 4830 lbs	2	2 - 1	8-21-84	Stuck in Barrel
14	5-C	195	1054 MV = 5270 lbs	2	2 - 2	8-22-84	
15	1-D	155	456 MV = 2280 lbs	2	2 - 3	8-22-84	
16	2-D	120	406 MV = 2030 lbs	2	2 - 4	8-22-84	
17	3-D	163	468 MV = 2340 lbs	2	2 - 5	8-22-84	
18	4-D	195	536 MV = 2680 lbs	2	2 - 6	8-23-84	
19	5-D	175	540 MV = 2700 lbs	2	2 - 7	8-23-84	
20	5-A	300	750 MV = 3750 lbs	2	2 - 8	8-23-84	

TABLE 2. Test Result Averages

Band	Measured Force	Foundation Moment
A	4430 pounds	22,150 in-lb
B	4970 pounds	24,850 in-lb
C	5160 pounds	25,800 in-lb
D	2410 pounds	12,050 in-lb

exerted on the ramp for test 3-A is unknown, but it was at least 5000 pounds. This will necessarily bring down the average force for band A. The differences between bands A, B, and C, are therefore not significant, and are in fact not statistically significant, because of the low number of successful tests. It is, however, important to note the differences between the first three bands and band D. Band D provided only about half of the foundation moment of the three previous bands. In the analysis work that was done to model these three bands (to be discussed in the following section of this report), we obtained a similar difference in the potential foundation moment. This is an important result in that it could give credence to the finite element method as a ranking tool for several different rotating band designs.

ANALYSIS OF THREE OF THE FOUR BAND GEOMETRIES

Finite element computations were made using three of the four band geometries. Figures 3, 4, and 5 show hidden line views of the three dimensional models used for the finite element work. In all cases, the finite element program ANSYS(*) was used for the computations. Figure 3 is the model used to estimate the foundation moment for Band A. Figures 4 and 5 are representative of Bands C and D, respectively. The model shown in Figure 3 is very similar to what was used for the three dimensional analysis last year. It is, in fact, the same general model, with a circumferential mesh refinement, and some slight changes in the band area. The models represented by Figures 4 and 5 are somewhat different. The data storage requirements of the model represented by Figure 3 were very large. In an attempt to reduce the sizes of the required data files, the interior portion of the aluminum was modelled by significantly fewer elements. Even with this reduction in the number of elements, the analyses using the meshes shown in Figures 4 and 5 required some 60 megabytes of free disk space on an APOLLO DN420(*) computer. This is a significant expenditure of disk resource, and one not to be taken lightly. Allocating that much space to a single problem on the computer posed a significant burden on other users of the system, and could only be accomplished with the cooperation of all users.

The finite element computations this year differed from the three dimensional calculations performed last year in two major respects. First, there were three different geometries analyzed this year rather than the single geometry used last year. Secondly, non-linear properties were used for the nylon bands in this year's analysis. The properties of the band material were assessed as a portion of this project, but are reported separately, as stated in the introduction to this report. Figure 6 is a representative stress-strain curve for the nylon material, and is the one used for the analysis performed this year. Using this material curve made the analysis non-linear, with an attendant increase in the run times and complexity of the analysis.

Table 4 presents the results of the analysis performed this year. There were two different input displacements used for each of the three models, 0.1 inches (2.5 mm) and 0.3 inches (7.6 mm). The tests which were run to determine foundation moment used an input displacement of 0.09 inches (2.3 mm), and therefore should be compared to the 0.1 inch analysis results. The results of the analysis predict a foundation moment roughly twice that tested. This is the result of our inability to accurately predict the boundary conditions at the band to gun bore interface. It is evident that a good portion of the nylon band loses contact with the gun barrel inner surface during the input of the angular disturbance in the test. Even with a fairly large interference (approximately 10 mils or .25 mm) between the gun bore and the outer diameter of the band, there is still significant loss of contact. This is the nature of the experimental apparatus, and

* ANSYS is a proprietary Engineering Analysis computer program owned, distributed, and supported by Swanson Analysis, Inc., Houston, PA.

* APOLLO Computer, 15 Elizabeth Road, Chelmsford, MA. DN420 model is a monochrome workstation computer system.

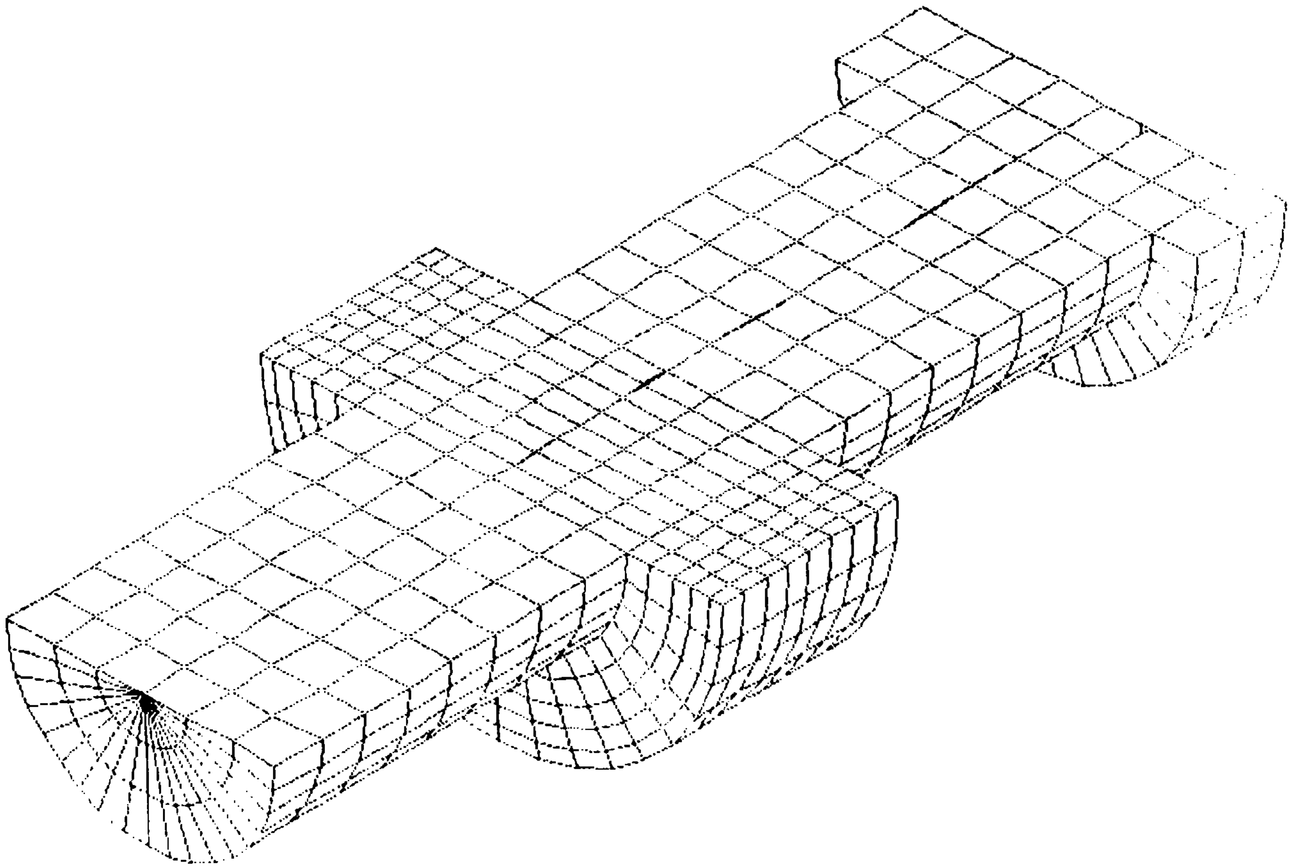


FIGURE 3. Band A Finite Element Model

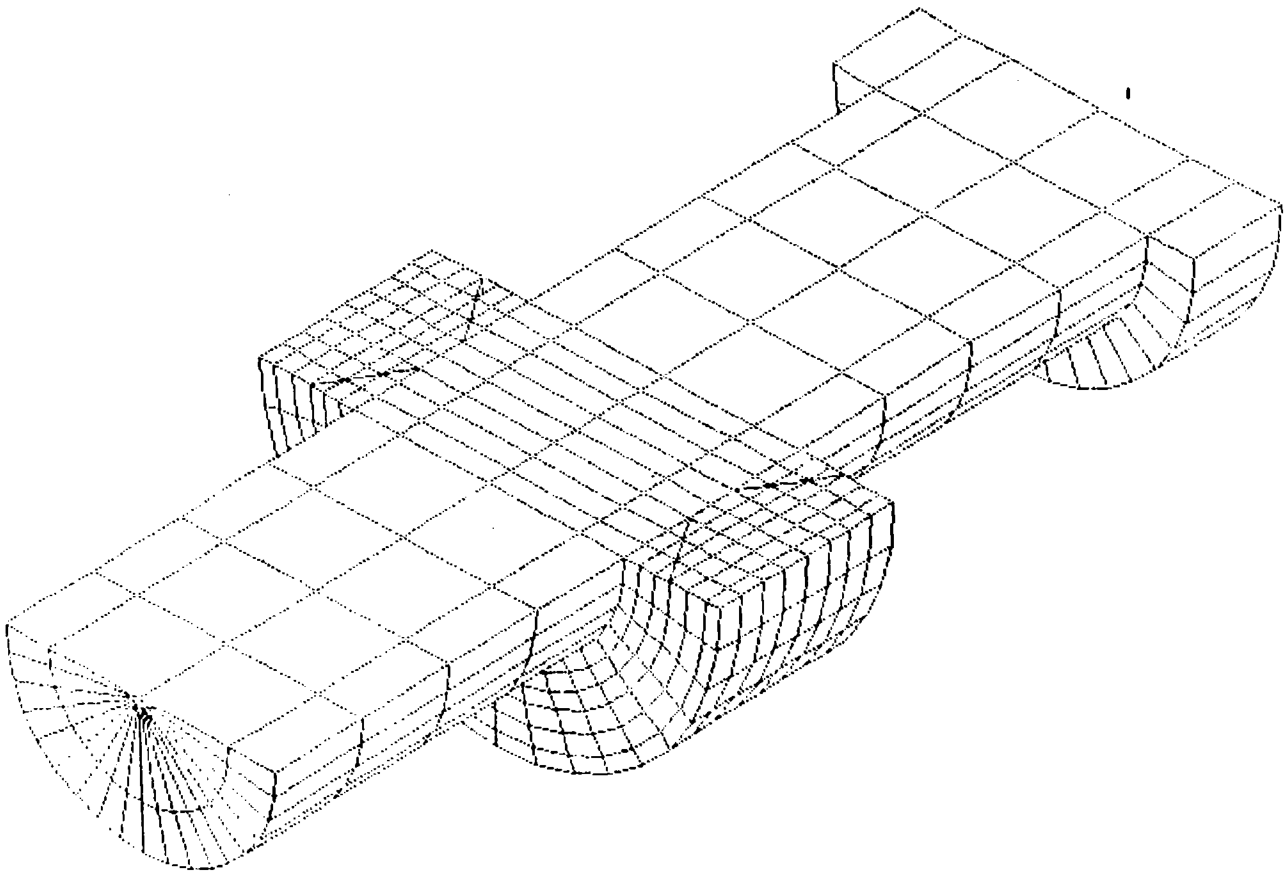
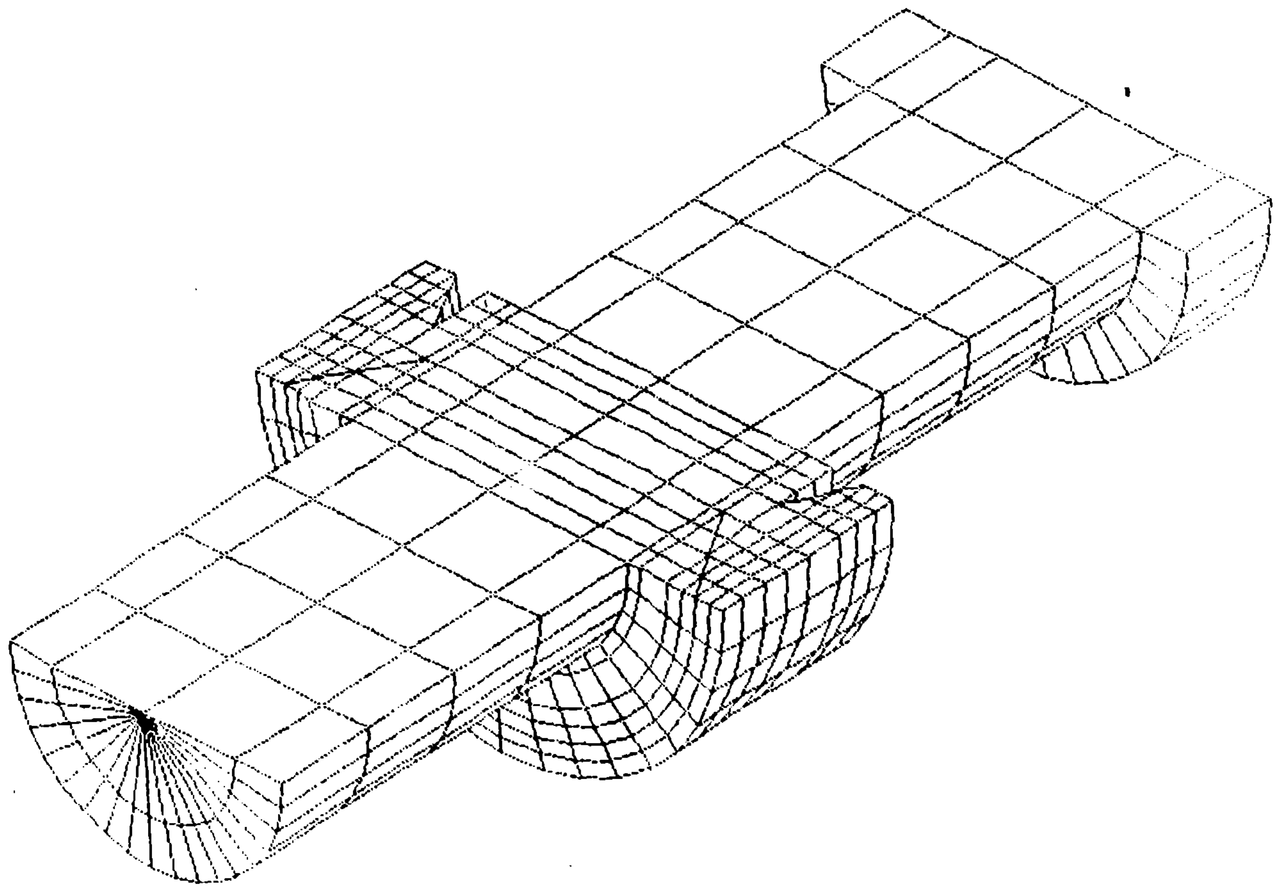


FIGURE 4. Band C Finite Element Model



<u>FIGURE 5</u>. Band D Finite Element Model

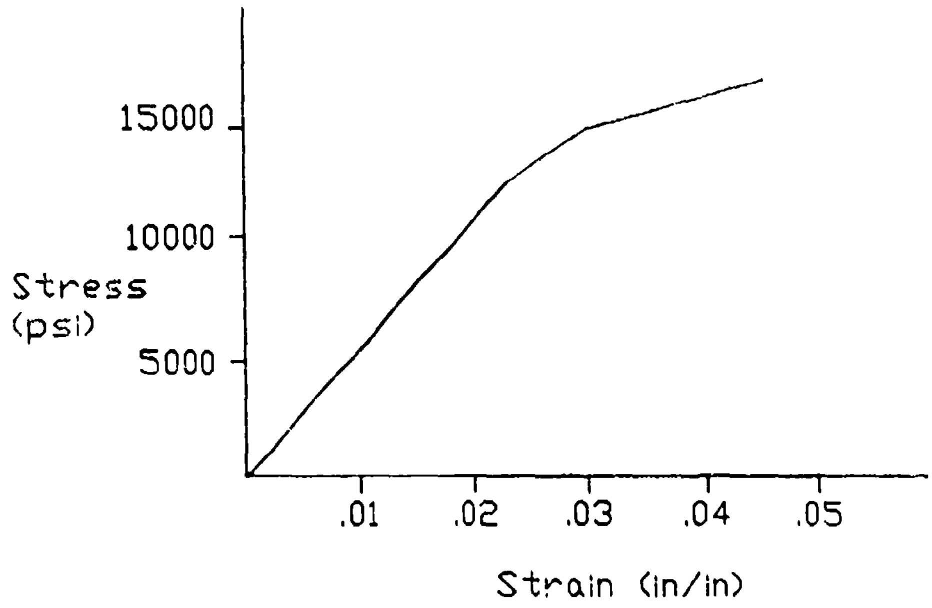


FIGURE 6. Nylon Stress-Strain Curve

very little can be done to alleviate the problem. The bands can be machined with a larger interference, but this poses problems in loading and firing the projectiles. The hydraulic ram that is used to load the projectiles is limited to 9 tons of ram force. We use approximately half of the capacity of the ram to insert the projectiles which have a 10 mil (.25 mm) interference. Last year we attempted to load a projectile with a 30 mil (.75mm) interference, and were unsuccessful.

TABLE 3. Finite Element Results

Band Geometry	Force for .1 inch deflection	.3 inch deflection
Straight (band A)	13,000 pounds (5900 kg)	27,500 pounds (12500 kg)
V-band (band C)	11,400 pounds (5180 kg)	22,800 pounds (10400 kg)
V-notch (band D)	6,340 pounds (2880 kg)	15,300 pounds (6950 kg)

It is clear that the boundary conditions of the test and the analysis are different. We used material properties assessed from the material used to construct the bands. The finite element results follow the pattern of past analysis, and show a characteristic drop in magnitude because of the yielding of the nylon band material. The only major discernible differences between analysis and test, therefore, are the boundary conditions which should be applied to the models. These differences arise in two forms. First, we do not know precisely the magnitude of the input angular disturbance. The facet used will give nominally a 0.09 inch (2.3 mm) deflection to the rear of the projectile. This is if the projectile is centered correctly in the gun barrel, and if the projectile is made correctly (i. e. straight). This difference should show up in differences between tests. There are some differences between the results of the tests, but they are consistent enough that this difference should be small. The magnitude reported is also the average of several tests, and therefore should be fairly free of defects in the manufacture of the projectile or bands, or of the differences in loading of the projectiles. The second form of difference is the fact that some of the band will lose contact with the gun barrel during the test, as stated above. To assess the magnitude of this phenomenon, we must look at the geometry of the band to gun barrel interface during the input angular disturbance. Figure 7 is the triangle which is made between the gun barrel and the projectile band at the barrel to band interface. For an input disturbance at the rear of the projectile of 0.1 inches (2.5 mm), the length of the shortest side of the triangle in Figure 7 is about 40 mils (1.0 mm). As stated above, it is beyond the physical limitations of our ram to load a projectile with this magnitude of interference.

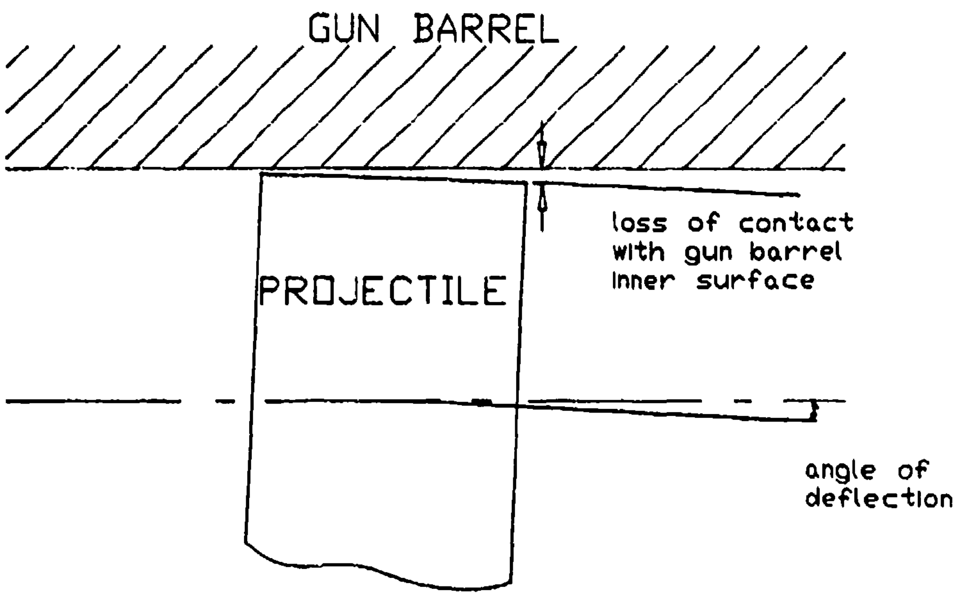


FIGURE 7. Geometry of Barrel/Band Interface During Angular Disturbance

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The major conclusion which can be drawn from the first three years of this project is that the foundation moment is indeed large. In past years it has been estimated to be approximately equal in magnitude to the overturning moment generated by having the center of gravity two thirds of a caliber behind the center of transverse rotation at maximum launch acceleration. Early in the ballistic cycle, when acceleration loads are relatively small, the foundation moment is probably the dominant transverse force on the projectile. The conclusion reached from the test and analysis performed this year has proved to further substantiate this result, and has extended it to the geometries characteristic of current APFSDS projectiles. The foundation moment measured using this newer geometry was approximately half that measured using the bands from previous years. However, it is not clear that the tests are entirely characteristic of an actual gun firing. In any case, the test results still indicate that the foundation moment is still most probably the dominant force on a single bore contact projectile early in the ballistic cycle.

Another conclusion which can be reached from the work done in the past three years is that the reaction of any projectile to force disturbances in the gun barrel will indeed be complex and non-linear. The interior ballistic environment is extremely violent, and of very short duration. Common engineering assumptions are not necessarily valid in such an environment. Performing finite element structural computations on even our relatively simple test apparatus and projectile has proven to be complex and not without significant difficulties.

The measurement of the foundation moment has progressed about as far as is practical in light of the results to date, and the limited funding available at BRL for this work. What has not been estimated to date is the potential for the nylon band to damp transverse oscillations of the projectile. To begin to write equations of motion for the projectile in the gun barrel, we must know something about damping. The work which has been proposed as a continuation of the foundation moment project is intended to measure damping of the projectile in the gun barrel. After the damping has been measured, we will at least be able to write a set of equations of motion for the projectile in the test apparatus. This information should feed directly into work currently being funded by BRL to attempt to write the complete set of equations of motion for a projectile in the interior ballistic environment.

APPENDIX A

OSCILLOSCOPE TRACES FOR TESTS WITH GOOD DATA AND BAND MEASUREMENTS BEFORE AND AFTER TESTS

The following pages contain plots of the stored oscilloscope traces for each of the tests which produced data. All of the traces have a characteristic shape with the projectile riding up the ramp, and then precipitously falling off of the ramp. Note that in every instance the force riding up the ramp is non-linear with time, and that the curve is bowed outwards. If the relationship between angular disturbance and foundation moment were linear, this curve should be bowed upwards. The effect that we witness in these plots is most probably a combination of the yielding of the nylon band and the geometric non-linearity of the band/gun bore interaction. It should be also noted that each test had a different time duration for the projectile ride up the ramp. The time recorded for the shortest event was approximately 6 milliseconds, whereas the longest event took nearly 70 milliseconds. This is more than an order of magnitude difference in the ramp contact time. The differences in contact time correlate only with the pressure required to fire the projectiles, and not the ultimate magnitude of the foundation moment itself, and are therefore not deemed significant.

The oscilloscope traces are labelled according to the test number shown in Table 1 of the main report. That is, Spec 4 is specimen 4 or band number A-4.

The last page of this appendix contains the band measurements both before and after the tests. The measurements are approximate, in that they were taken with a hand-held caliper. The measurements do show one problem with the experiment, however, in that they are inconsistent, and do not seem to correlate with the measured foundation moment. It would seem that a band with a greater interference would have a larger foundation moment, but that does not seem to be the case if the measurements are taken at face value. A plausible explanation of this inconsistency, and the one to which we ascribe, is that the measurements are not correct, and that a more accurate measurement technique should be used in any future testing.

TABLE A-1. Band Measurements Before and After Tests

Test	Band II	Front Before		Rear Before		Front After		Rear After	
		1	2	1	2	1	2	1	2
1	1-A	5.115	5.117	5.116	5.117	5.107	5.105	5.108	5.108
2	2-A	5.112	5.113	5.115	5.116	5.107	5.111	5.108	5.109
3	3-A	5.113	5.114	5.118	5.114	5.102	5.105	5.105	5.105
4	4-A	5.115	5.111	5.117	5.118	5.110	5.107	5.114	5.115
5	1-B	5.129	5.128	5.125	5.124	5.121	5.121	5.119	5.121
6	2-B	5.123	5.124	5.120	5.123	5.122	5.124	5.123	5.122
7	3-B	5.124	5.125	5.125	5.123	5.114	5.112	5.113	5.112
8	4-B	5.112	5.112	5.112	5.113	5.112	5.114	5.116	5.114
9	5-B	5.111	5.115	5.114	5.114	5.113	5.114	5.112	5.112
10	1-C	5.115	5.115	5.110	5.116	5.114	5.114	5.112	5.118
11	2-C	5.114	5.114	5.116	5.118	5.113	5.115	5.113	5.115
12	3-C	5.115	5.117	5.113	5.118	5.115	5.115	5.112	5.115
13	4-C	5.115	5.116	5.117	5.116	5.114	5.116	5.114	5.113
14	5-C	5.117	5.114	5.112	5.114	5.112	5.113	5.112	5.113
15	1-D	5.110	5.111	5.107	5.113	5.112	5.108	5.110	5.109
16	2-D	5.110	5.112	5.112	5.113	5.110	5.113	5.110	5.109
17	3-D	5.117	5.111	5.112	5.111	5.116	5.113	5.112	5.108
18	4-D	5.109	5.112	5.110	5.110	5.111	5.112	5.107	5.111
19	5-D	5.116	5.114	5.113	5.108	5.112	5.112	5.113	5.108
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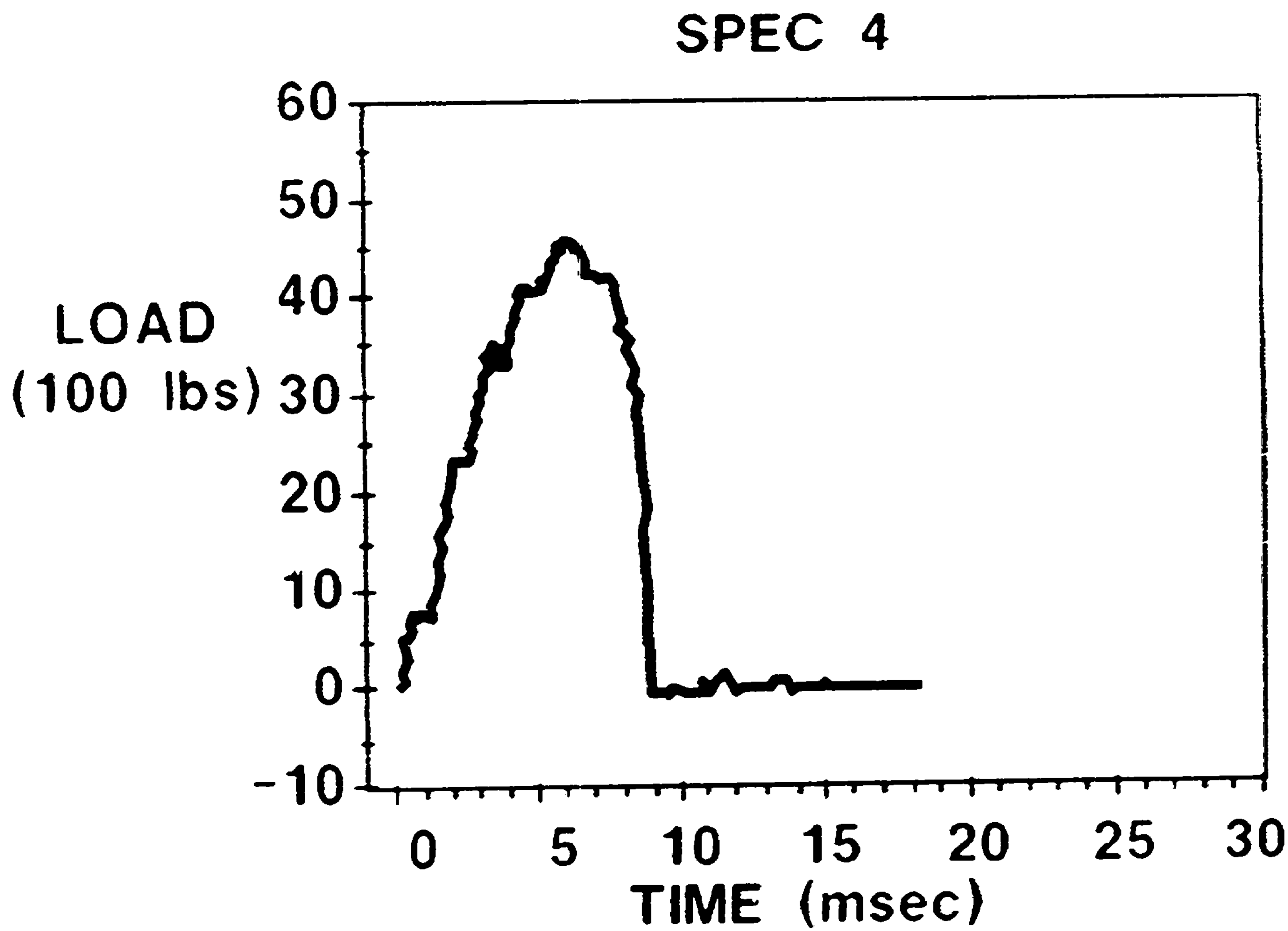
SPEC 4
LOAD
(100 lbs)
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50
40
30
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0
-10
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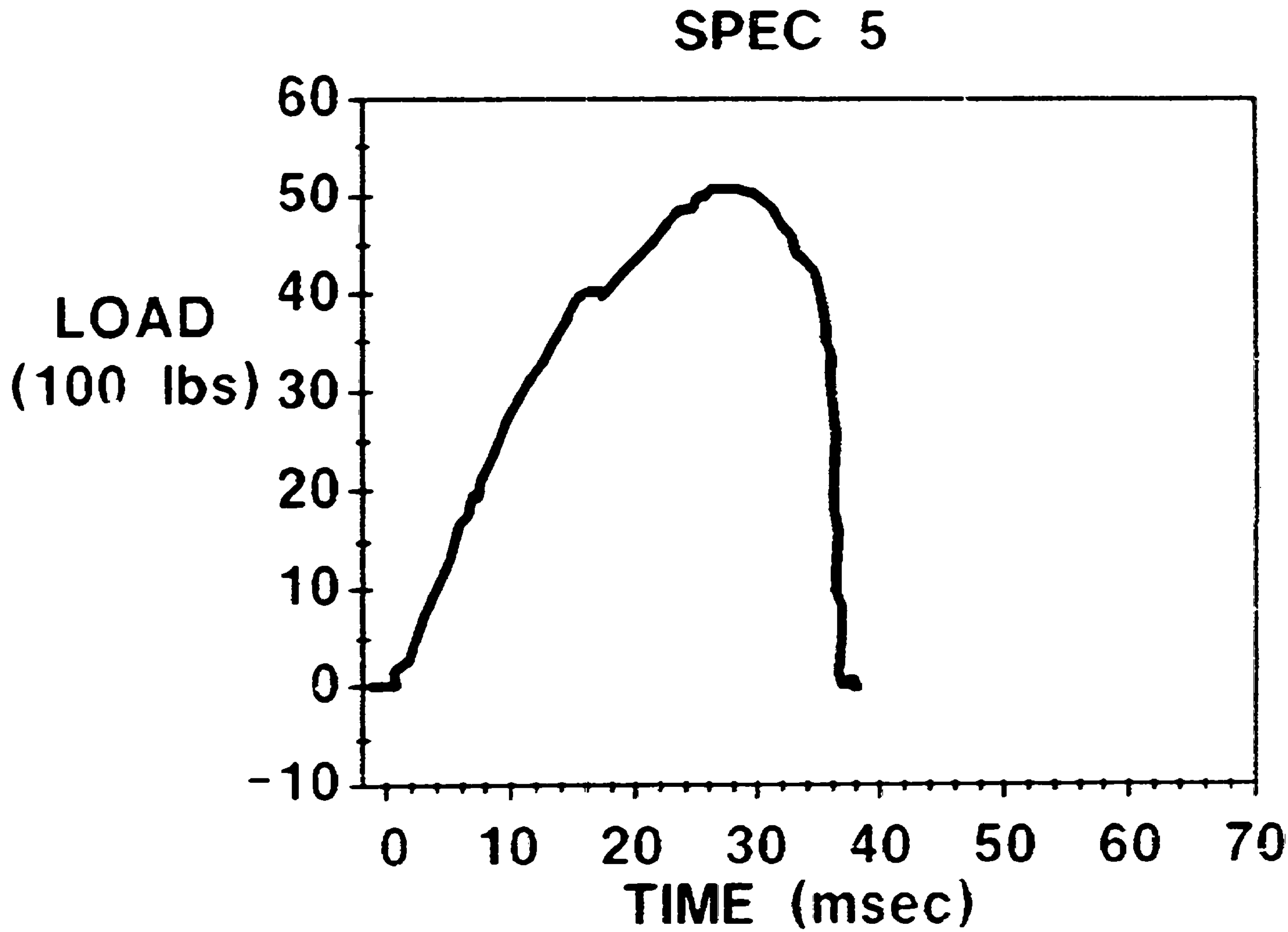
5
10
15
20
25
30
TIME (msec)


SPEC 5
LOAD
(100 lbs)
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30
40
50
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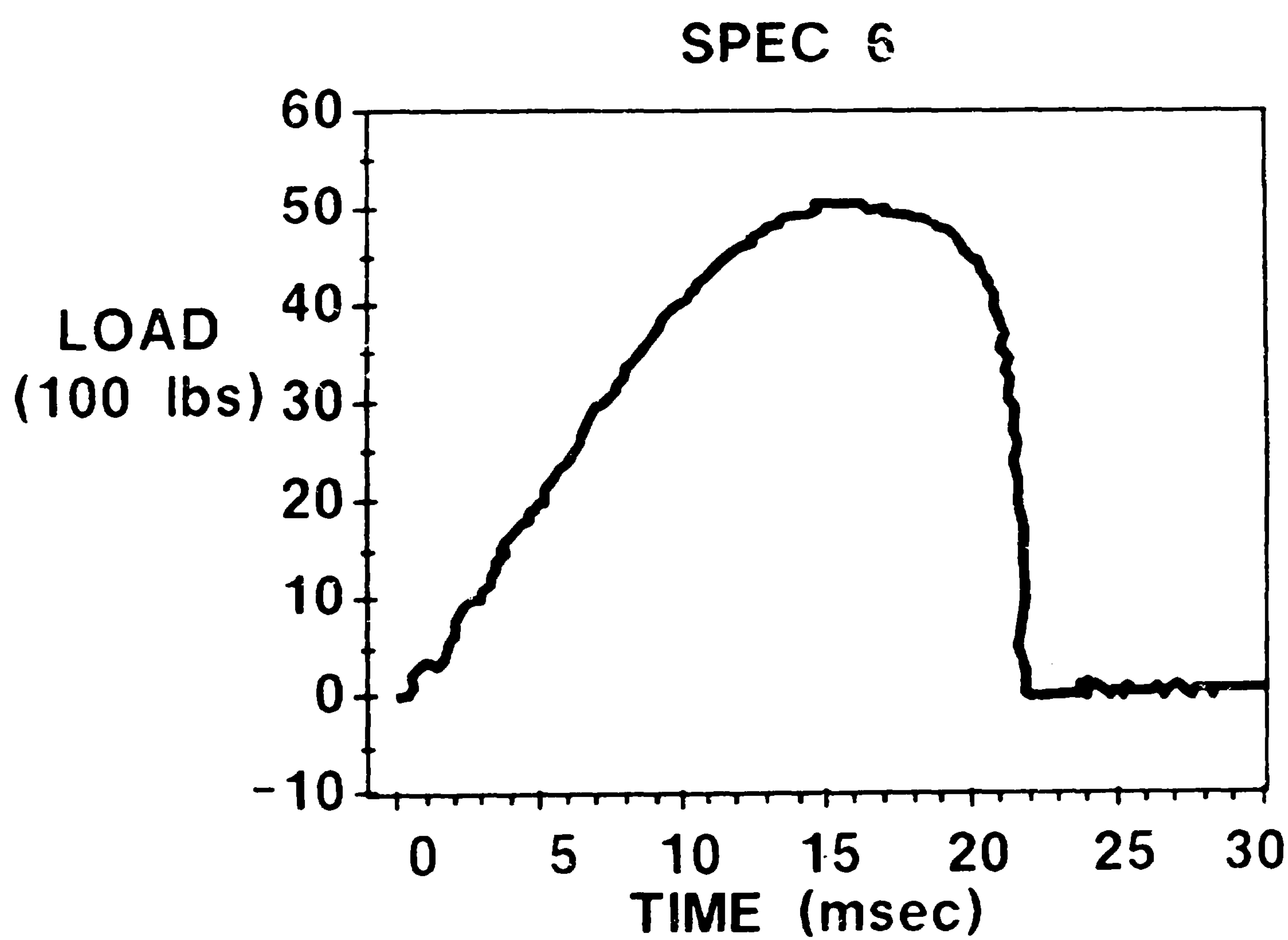
70
TIME (msec)



SPEC 6
LOAD (100 lbs)
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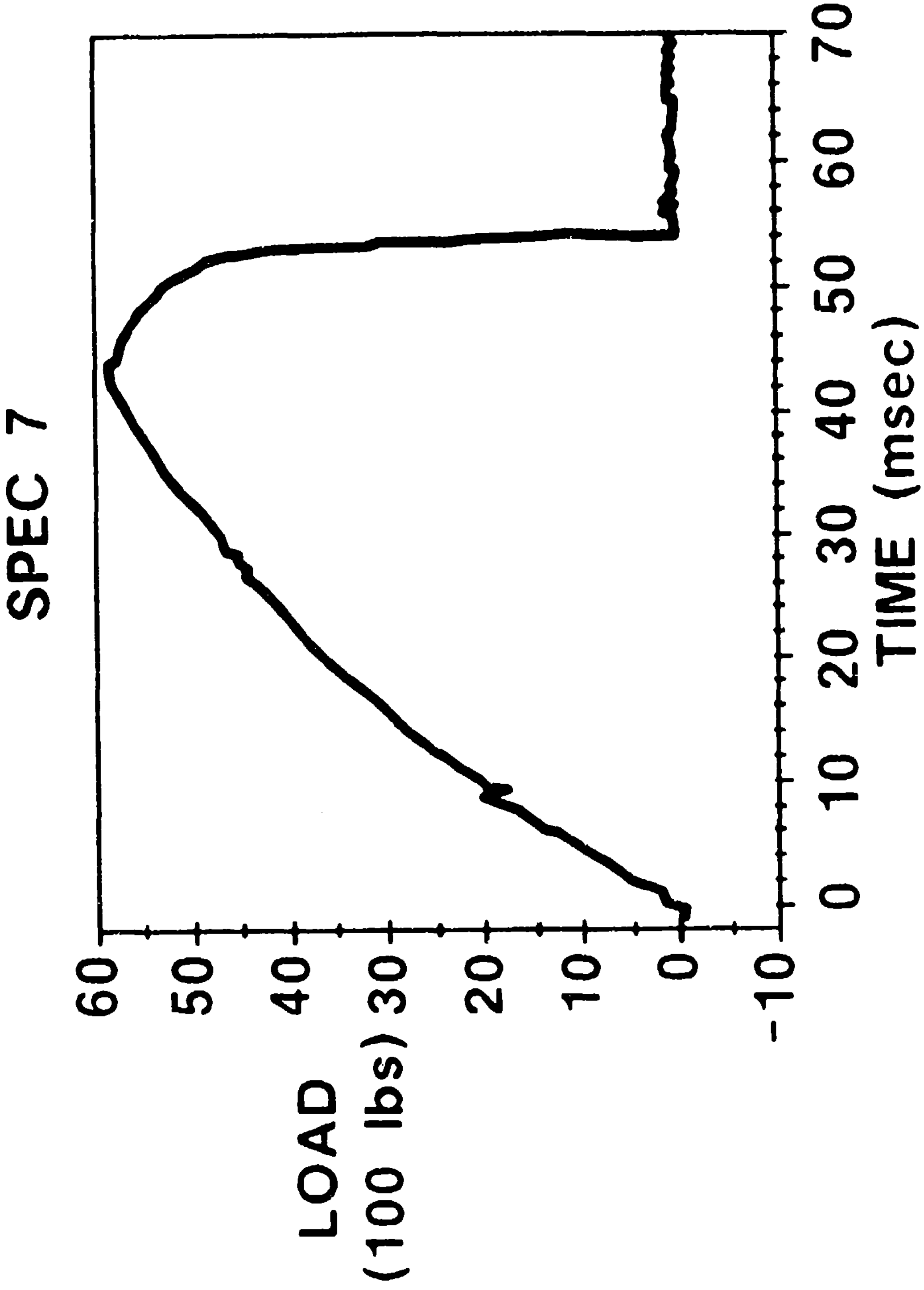
TIME (msec)


SPEC 7
LOAD
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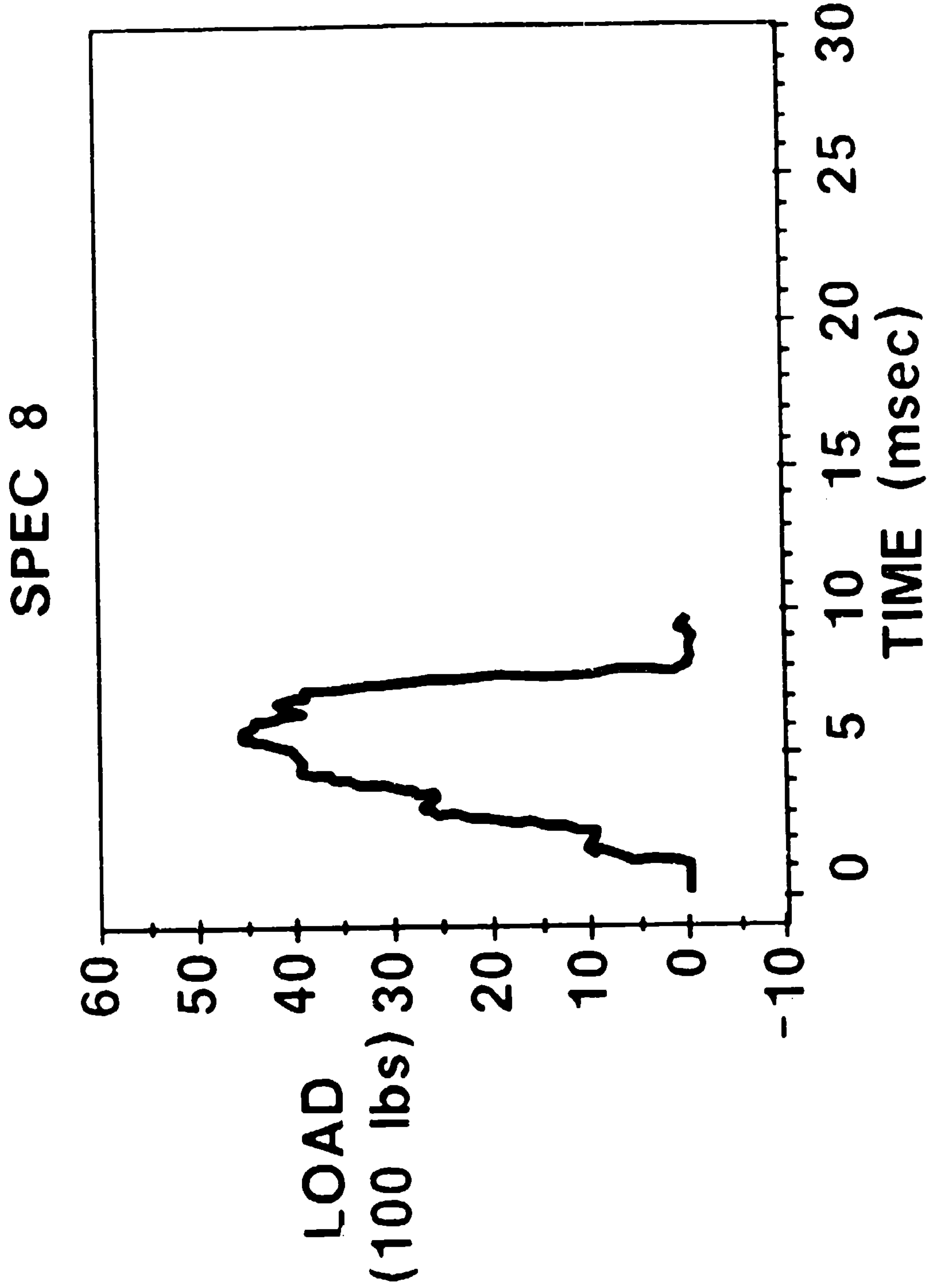
TIME (msec)



SPEC 8
LOAD
(100 lbs)
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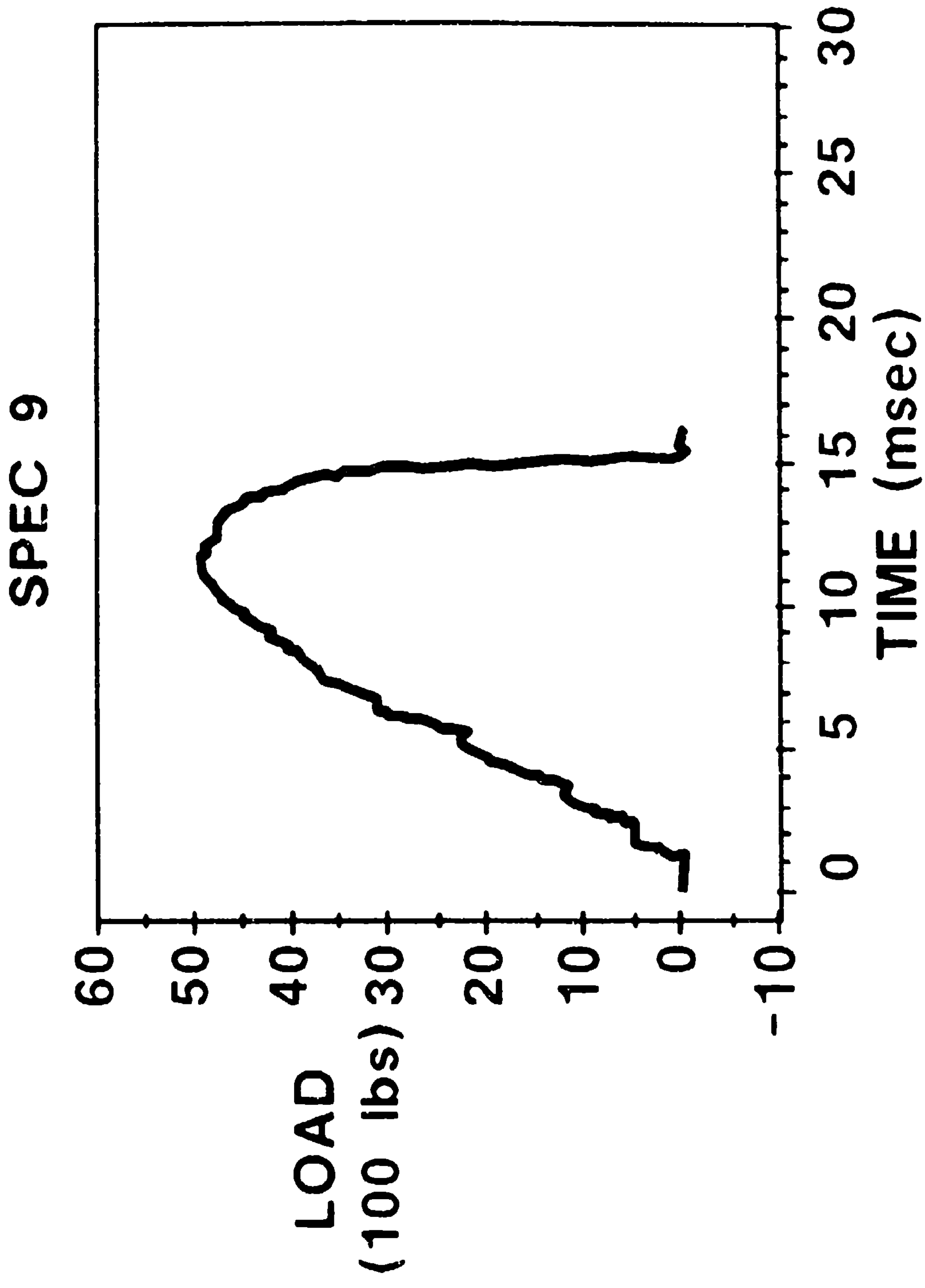
TIME (msec)


SPEC 9
LOAD (100 lbs)
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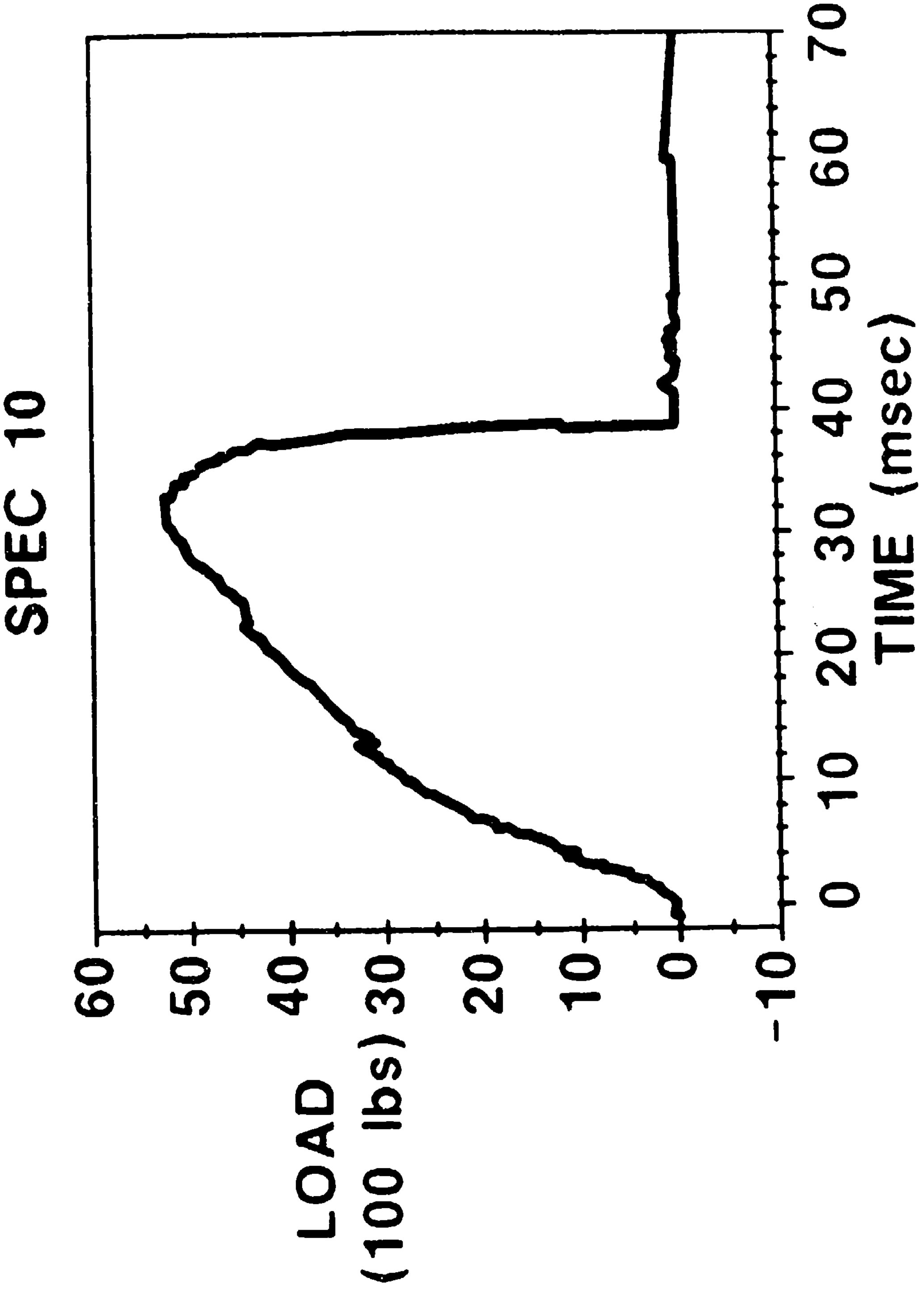
TIME (msec)


SPEC 10
LOAD
(100 lbs)
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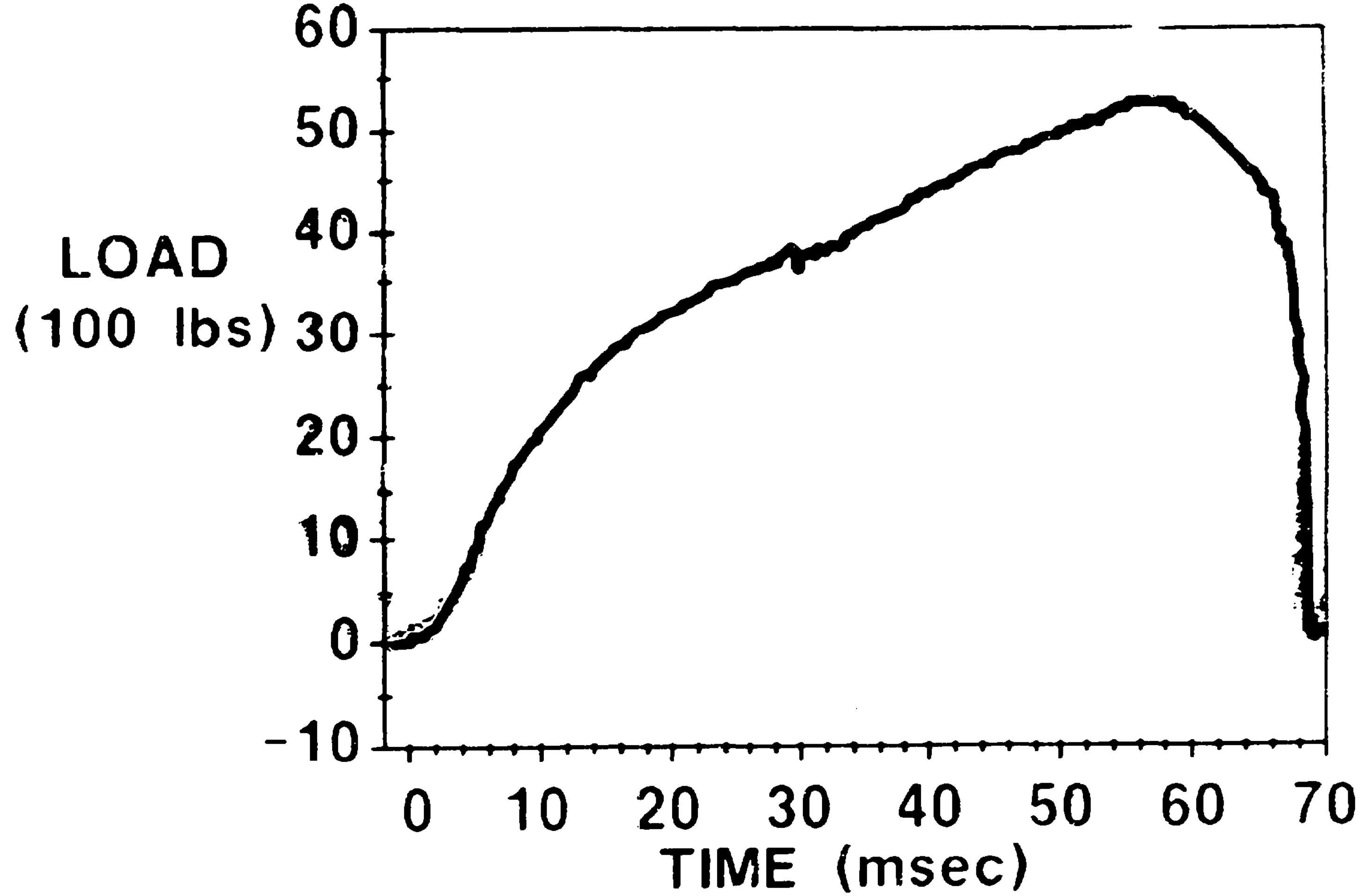
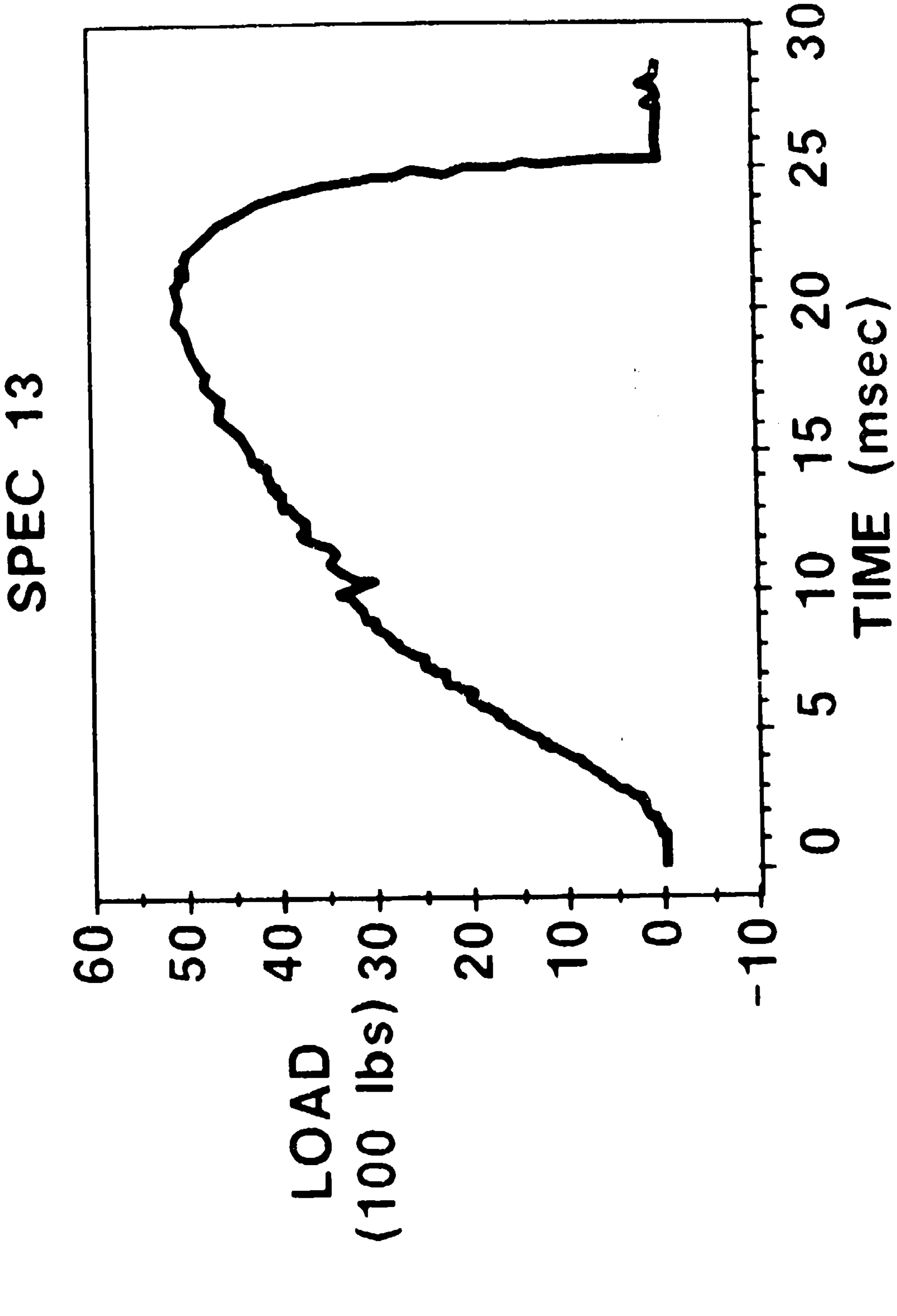
TIME (msec)

SPEC 12




SPEC 13
LOAD
(100 lbs)
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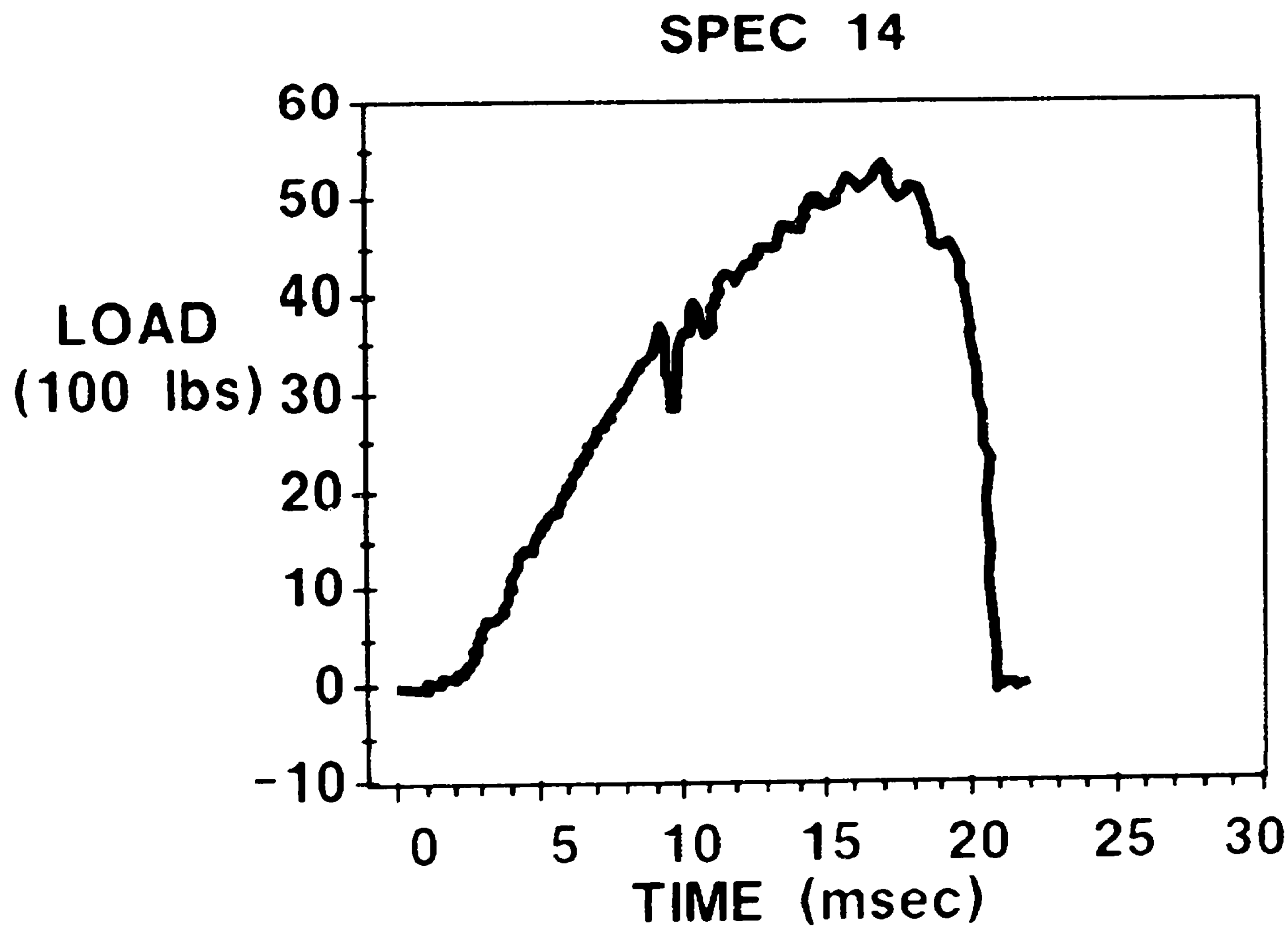
TIME (msec)


SPEC 14
LOAD
(100 lbs)
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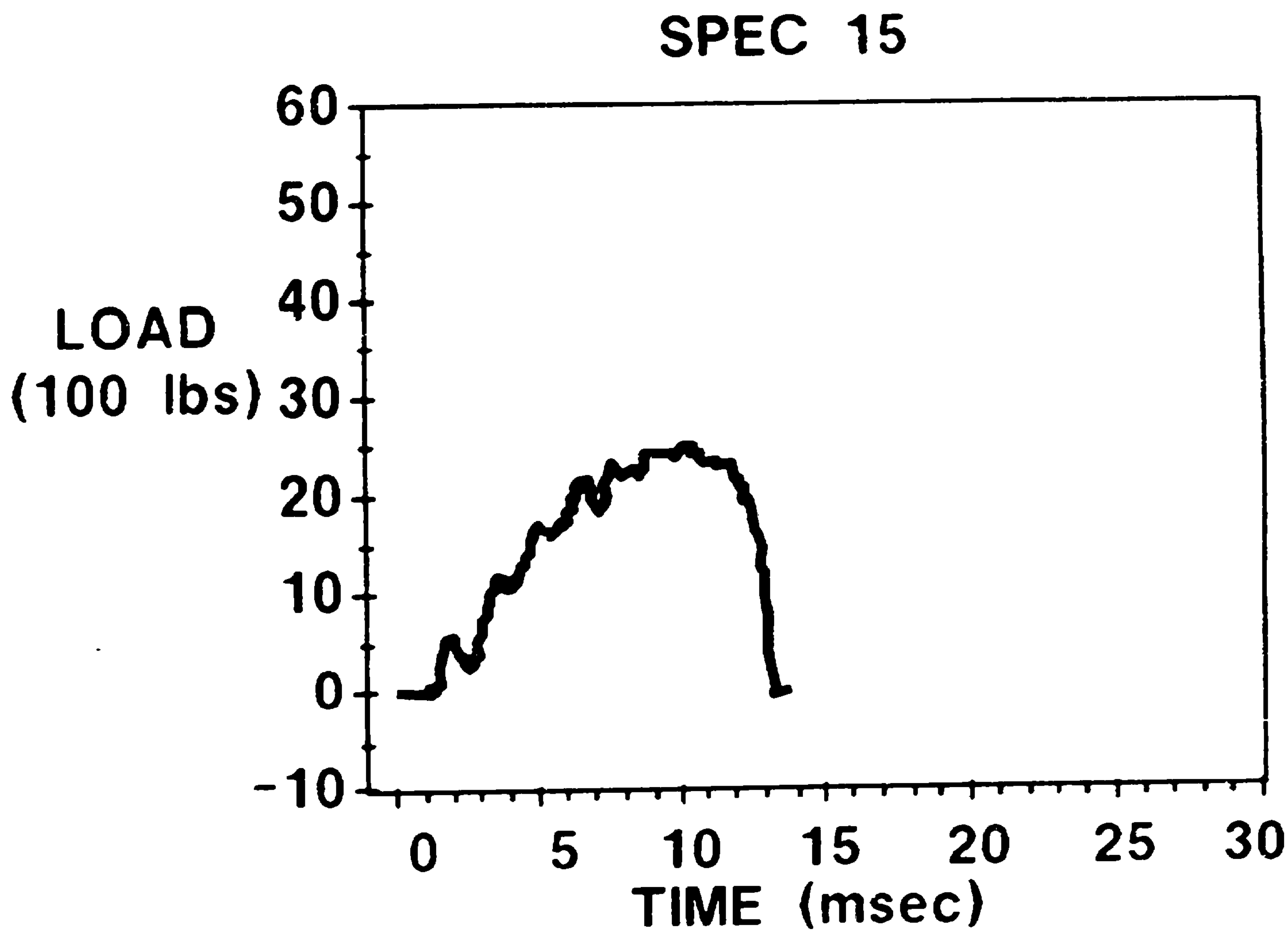
TIME (msec)


SPEC 15
LOAD (100 lbs)
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-10
0
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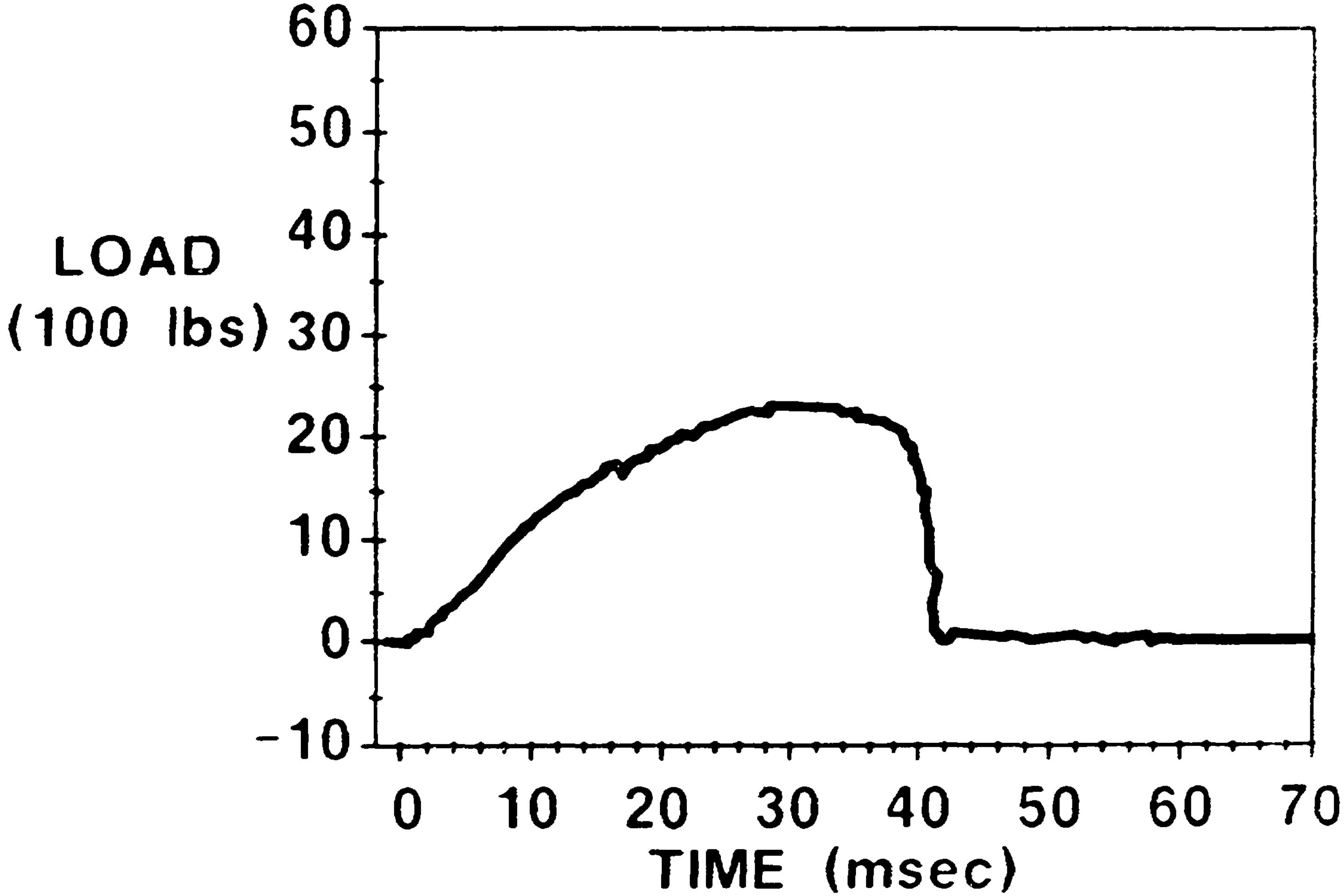
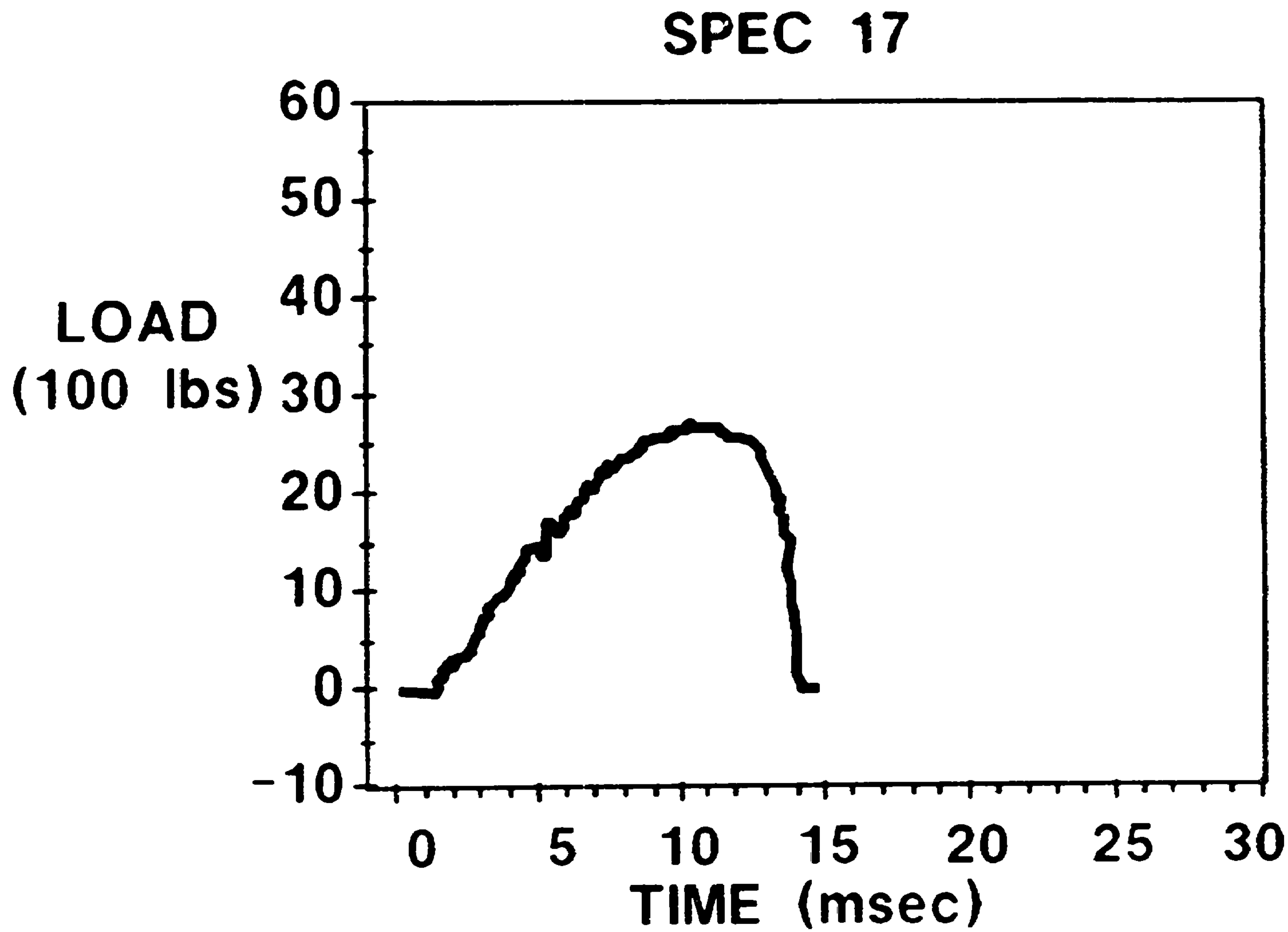
15
20
25
30
TIME (msec)

SPEC 16




SPEC 17
LOAD
(100 lbs)
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-10
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15
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25
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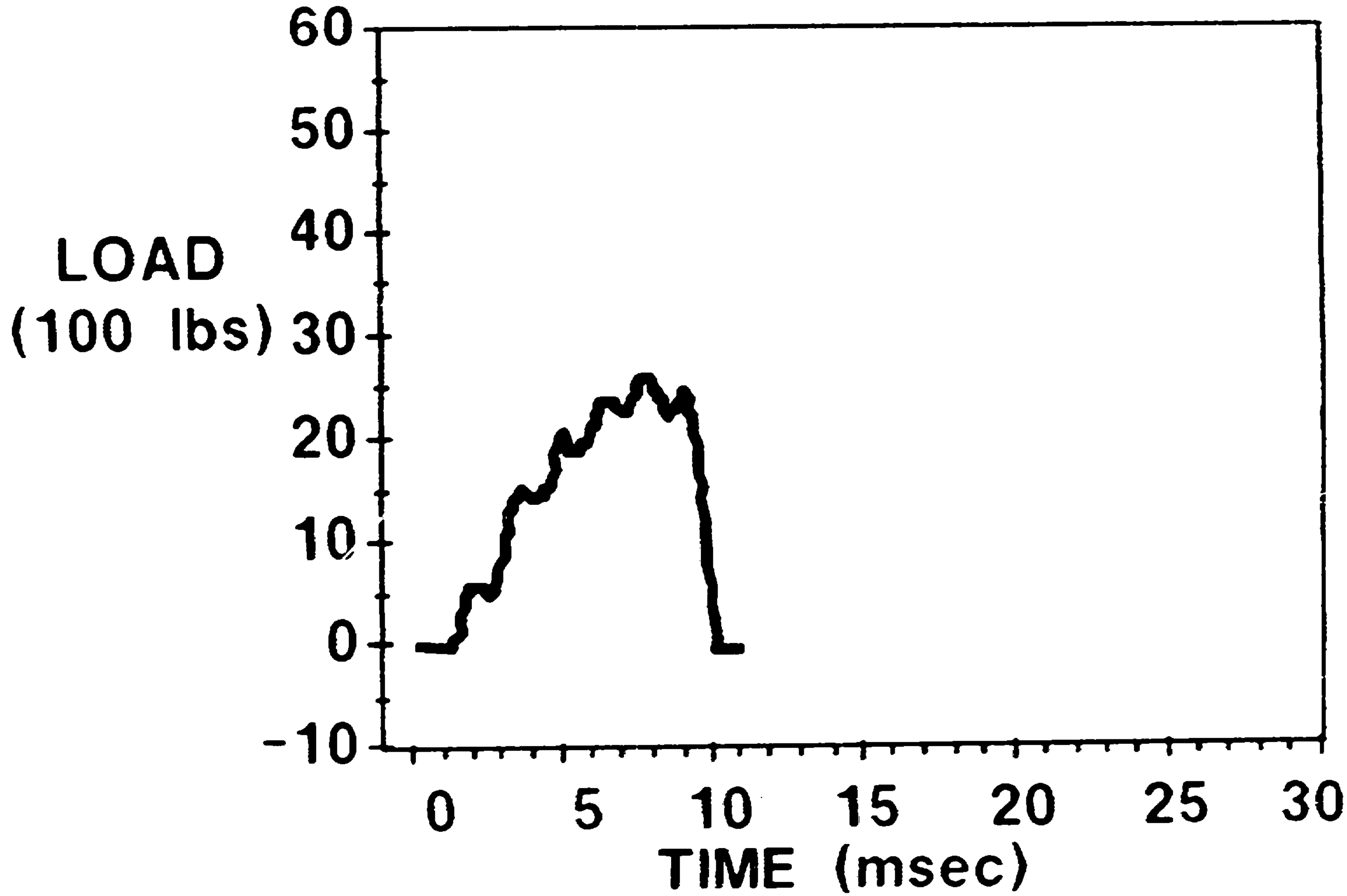
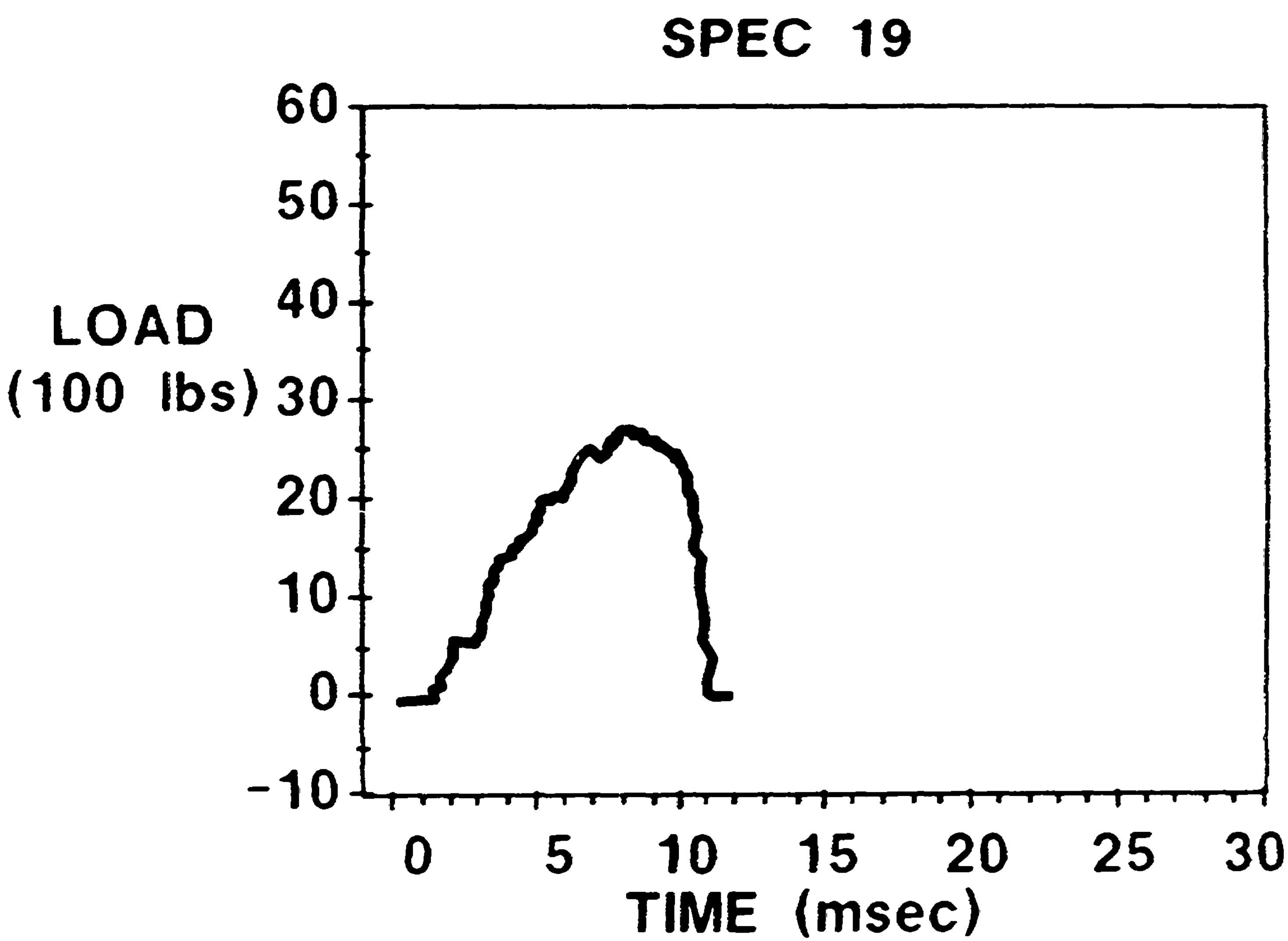
TIME (msec)

SPEC 18




SPEC 19
LOAD
(100 lbs)
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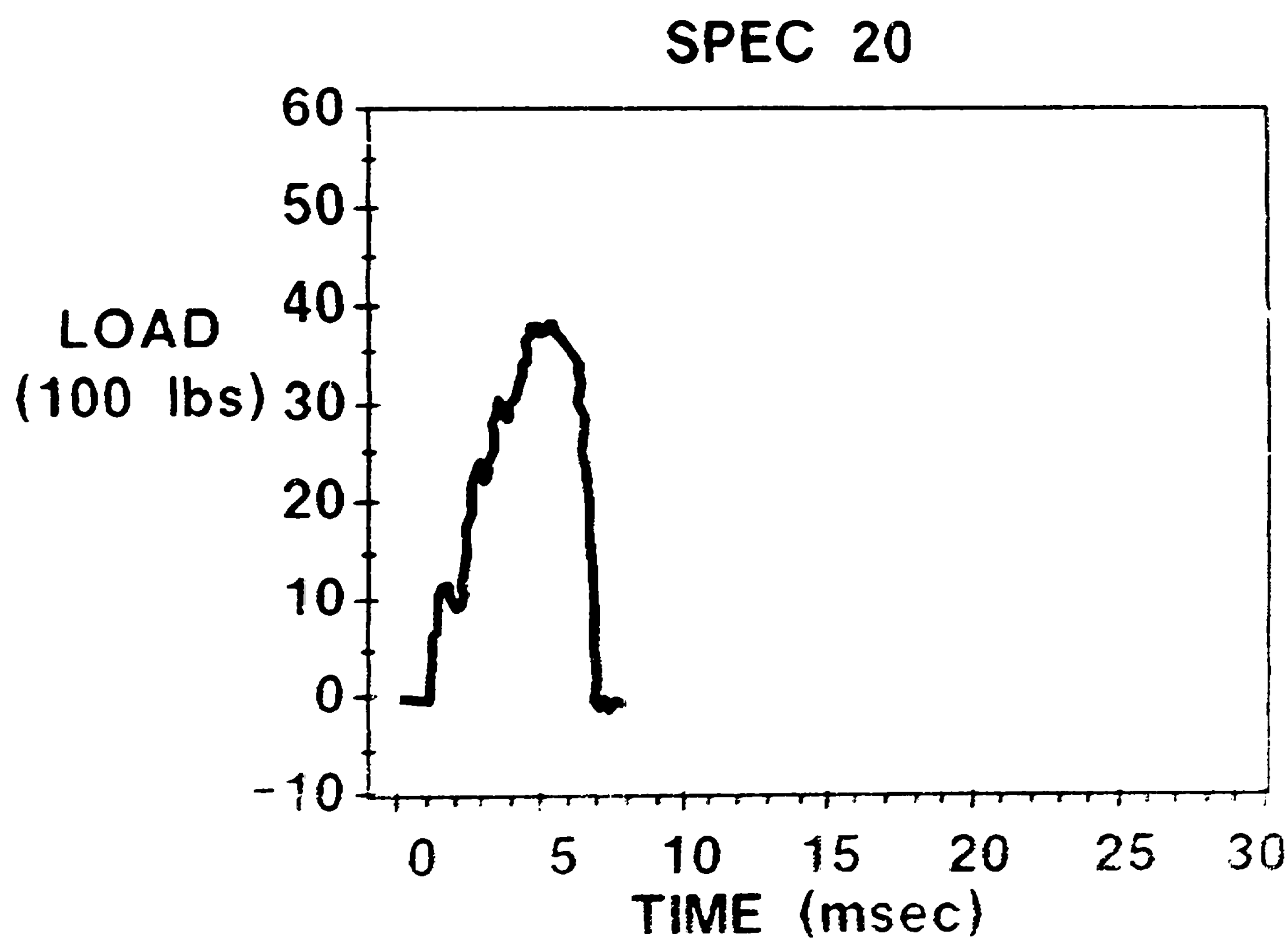
TIME (msec)


SPEC 20
LOAD
(100 lbs)
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50
40
30
20
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0
-10
0
5
10
15
20
25
30
TIME (msec)

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